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INJURY BIOMECHANICS RESEARCH
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ONGOING INVESTIGATION OF BRAIN-INJURY KINEMATICS

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INTRODUCTION

A principal feature of this study is the measurement of relative brain motion both with respect to the skull as well as with respect to other areas of the brain. Using a high-speed bi-planar x-ray system and neutral density markers, all components of the strain tensor for a relatively small volume of brain can be determined. Relative kinematics between the brain and skull can be determined from implanted neutral density accelerometers and extracorporeal accelerometer arrays.

Head injury is still the most difficult and expensive injury in our society. It constitutes approximately 50% of the mortality and morbidity in automotive related injuries and are a significant problem in falls as well as in intentional injuries. The present working hypothesis is that shear strain is responsible for diffuse axonal injury (DAI). This hypothesis can be tested by conducting impact tests on living animals, performing an autopsy to determine the areas of the brain affected by DAI and developing a finite element model of the animal brain to identify areas of high shear stress. However, animal brains have a very different anatomy and injuries sustained by these brains cannot be readily translated to human injuries in terms of where the injury might be and if the same impact severity will cause the same level of injury. Therefore, cadaver testing should be conducted in conjunction with animal testing. Although cadaveric specimens are incapable of developing DAI, impacts to cadaveric heads can produce measurable relative motion of the brain with respect to the skull, using neutral density x-ray opaque markers and a newly available bi-axial high-speed x-ray unit. These data can also be used to validate the 3-D finite element model of the human brain designed by Zhou et al., 1995. Both the strain data and model predictions can then be compared with clinical data from victims of head impact who have sustained DAI and subsequently expired from their injuries. The location and approximate direction of the impact are known and these victims have undergone a complete autopsy with histological examination of their brain to determine the extent and location of their DAI. This comparison will reveal whether shear strain or some other mechanical parameter is responsible for the observed DAI.

There is no question that a better understanding of how the brain is injured will lead to more effective treatment and prevention. Localization of probable sites of DAI following impact can lead to treatment methodologies to minimize its development and thus reduce morbidity. Furthermore, if the shear strain hypothesis is valid, research can continue at a more microscopic level to try to understand how DAI develops in the brain. A detailed discussion of postulated brain injury mechanisms may be found in Hardy et al., 1994.

The portion of the study discussed herein focuses on the development and use of neutral density technology and a high-speed x-ray system to measure relative brain/skull kinematics. Two whole-body tests and one inverted isolated-head test are described, with the emphasis being on the whole-body testing. A discussion of other facets of this investigation may be found in King et al., 1994.

BACKGROUND

The development of neutral density technology is an ongoing effort to better understand the kinematics of brain injury and to determine any phenomena occurring in the brain tissue relative to the skull. This pursuit produces systems capable of measuring kinematic and dynamic quantities within the brain and of the skull as a whole. The systems developed under this program include triaxial neutral density accelerometers (NDA-3's), a rigid body kinematics transducer array (RBKTA), cranial pressure transducers (CPT's), reduced density targets (RDT's), trephine seals and a special cannula fixture for implanting these devices. In Figure #1 a collection of implants and their associated trephine seals are shown and a dime provides scale.

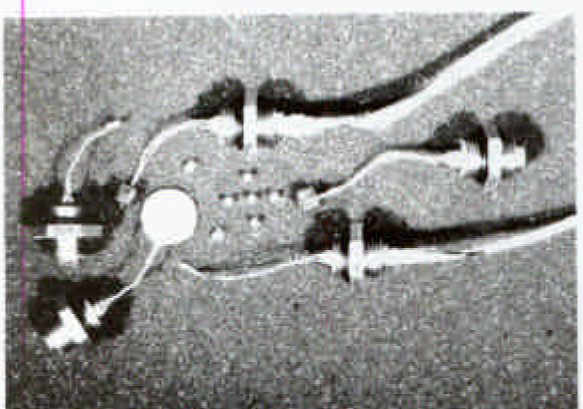

Figure #1: Implant collection, including CPT's (left), NDA-3's (right) and RDT's (center).

NDA-3's

The triaxial neutral density accelerometers are polyurethane foam filled, polyester resin shells that contain three mutually-orthogonal ICSensor's integrated accelerometer dice. The units displace 0.187 ml and have a density of 1.07 gm/ml. The piezoresistive bridges are wired in parallel, so each device requires only eight 36 gauge wires. Each NDA-3 is acrylic coated, and has a 1.5 mm gold ball fixed to the center of the bottom face. The two functional NDA-3's are implanted in the posterior aspect of the parietal lobes of the cadaver specimens on either side of the midline. The NDA-3's are designed to maintain their positions with respect to surrounding brain tissue during impact.

RBKTA

The rigid body kinematics transducer array consists of 24 ICSensors 8063-200 integrated accelerometer dice fixed to an 85 gm 7075 aluminum CNC machined fixture. The locations of the dice reduce positioning errors, as each seismic mass lies exactly on an axis of the fixture. It is capable of determining angular acceleration, angular velocity and linear accelerations of an impacted rigid body. Given these parameters it is possible to determine angular displacement, linear velocity and linear displacement of a rigid body. It is also possible to translate this information to determine kinematic quantities elsewhere on the rigid body, such as at the c.g. of a struck head, or at the initial location of an implanted NDA-3. The RBKTA uses a linear regression of differences between tangential accelerations vs. differences in radii to determine angular acceleration. Angular velocity is found from differences in radial accelerations. Accelerations at the origin of the mount are found from regression analysis also. The RBKTA is an improvement of the techniques used in the WSU 3-2-2-2 nine-accelerometer array, and may be seen in Figure #2.

Figure #2: An oblique perspective of the RBKTA.

CPT's

The cranial pressure transducers are 690 kPa range stainless steel units, model 060S, from Precision Measurement Corporation. They measure 1 mm x 2 mm x 0.5 mm and use a three-wire configuration. The mass of these devices is only 7.8 mg, and their geometry is well suited for maintaining position relative to surrounding brain tissue.

Therefore, adding the mass and size required to lower the density of the CPT's is not recommended. These units are implanted at the coup and contrecoup injury sites, which in initial testing correspond to the occipital and frontal lobe regions. A third transducer is implanted in the parietal lobe.

RDT's

The reduced density targets are made from thin-walled polystyrene tubing. The finished targets are 2.34 mm diameter cylinders 2.60 mm long. Gold granules 1 mm in diameter are fixed via cyanoacrylate in the center of the target tubing. The ends of the tubes are capped with thin sheets of styrene. The gold granules are made from 14k gold wire. The wire is cut into equal length slugs, and heated on a charcoal block with an acetylene reducing flame. As the gold forms a sphere, the copper is burned away. The gold ball then rolls into a water-filled crucible, where it is quenched. The density of the targets is at or below 2.01 gm/ml. These targets are designed to occupy a minimal volume, move with the brain and to not lacerate the brain during the impact. The RDT's fit smoothly through a custom-fit cannula fixture.

Trephine Seals

These seals are an integral component of the implanted transducers. They provide electrical connectivity as well as sealing, and cannot be separated from the transducers once installed. Miniature 3-10 pin Lemo connector inserts are used for wiring purposes. Miniature O-rings are installed on either side of the locating collar of the connector inserts. The inserts are captured within an internally-threaded set screw by compressing the O-rings around the collars using a threaded sleeve. The transducer wire connections are potted in epoxy. A thin retaining nut and larger O-ring are used to secure and seal the trephine seal to the skull. The trephine seals fit into thread inserts set in the skull. The transducers can be implanted and the seals installed without twisting wires.

Cannula Fixture

The cannula fixture consists of five brass tubes that are beveled at the insertion end, each having a steel rod stylet. The cannulas form a square pattern with one tube at the center of this square. Each of the corner cannulas are 10 mm from the center cannula. The cannulas are held in this pattern by an aluminum block and set screws. The insertion length of the cannulas can be adjusted depending upon implant location and cadaver anthropometry. The stylets are held in position by a second aluminum block. The center cannula and stylet are independently adjustable so that additional targets may be implanted more deeply or shallow than the main array of five, along the center line of the array. Four bolts around the perimeter of the cannula array allow the fixture to be aligned and positioned on the skull. The fixture is designed to be inserted only once. A typical array of seven targets would be implanted in a 1-5-1 scheme with the center target being 10 mm from the other six targets. This requires two adjustments of the center cannula and stylet after the initial insertion. This fixture is not used in the whole-body tests, but in the inverted isolated-head tests. It is shown in Figure #3.

Figure #3: The multi-target cannula fixture.

METHODS

In this section of the study, two types of tests are conducted: whole-body and inverted isolated-head tests. Although aspects of both tests are described, the concentration is on the whole-body testing conducted thus far, and the rationale behind the development of the severed-head testing methodology. Both types of testing require a mobile impactor, x-ray, and various imagers and impact fixtures. Each of these elements is outlined as well as the preparation and testing of the cadaver specimens. Figure #4 depicts a general test configuration in which most of these items may be seen.

Mobile Impactor

The mobile impactor is mounted to a small aluminum gantry that is cross-braced. The impactor has a 152 mm diameter face attached to a 25 kN (range) load cell. This assembly is driven by a 203 mm stroke pneumatic cylinder. The load cell has an inertia compensation accelerometer mounted to it. The cylinder is controlled by a solenoid fire valve, a manual safety valve and a small accumulator. The fire pressure is set via regulation of nitrogen gas. Since this is a directly-driven impactor (no free mass or pendulum), the firing duration must be closely controlled. Synchronization with the x-ray system is also very important. This is accomplished by an electronic controller designed to coordinate the data acquisition, camera, x-ray and impactor timing.

Figure #4: The Motion Analysis Laboratory of the Bone and Joint Center at Henry Ford Hospital. The x-ray image intensifiers are on the right side of the gantries, and the impactor is in the distance.

X-ray

The high-speed bi-planar x-ray unit is currently in use in the Motion Analysis Laboratory of Henry Ford Hospital. The output phosphor of the image intensifiers is capable of 3000 Hz response. The x-ray is a continuous, non-gated system. The system has two sets of x-ray heads and intensifiers mounted to a dual overlapping gantry fixture. Relative height, angle and distance adjustment between the two gantries is virtually limitless. However, the distance between each head and image intensifier is fixed at approximately 120 cm in the horizontal plane, and the angle of each pair is fixed in the vertical plane. Because the system is bi-planar, 3-D motion of x-ray opaque objects can be quantified. Images are captured from the rear of the intensifiers by either film, tape or digitally-based media. The output of the image intensifiers is monochromatic.

Imagers

Several types of imagers are used in this study, with yet another type to be employed in future testing. Fastax high-speed film cameras are no longer used. High-speed video cameras with a resolution of 512x512 pixels, 10 bit gray scale, frame rate of 1000 and tremendous anti-blooming capability are to be received soon. In recent experiments, video cameras with a resolution of 500x240 pixels, 8 bit gray scale and frame rate of 250 capture the x-ray images. Typically 25 mm lenses (f-5.6), infinite focus, shutter speeds (exposure times) of 1/2000 with an ASA of 1000 are used. For these cameras, the x-ray is generally set at 100 mA and 120 kVP for .5 sec. These cameras are now only used if the present imagers fail. Currently, Kodak RO imagers provided by the Technology Division of Lear Corporation are used. These cameras provide color images with a 384x512 pixel resolution. Exposure times of 200 micro-seconds with frame rates of 500 or 1000, depending on the speed of the impact, provide the best pictures.

Impact Fixtures

Two impact fixtures are currently in use in this study. For whole-body testing, a mobile suspension system resembling a gallows is used. The subject is suspended between the image intensifiers of the x-ray system, and in front of the impactor. The subject is fitted with a harness made of nylon webbing and steel cable. The steel cable is attached to a metal ring. The ring is slipped over a hook, or slider, suspended by the gallows. An acrylic spreader is used to keep the suspension wires away from the cadaver head and instrumentation. The cadaver head is positioned using tape strapped across the forehead area, attached to the support wires. The bottom of the gallows is constrained by the cadaver's mass. The ring slides off of the hook during impact. This suspension system interferes little with the impact or the imaging of the impact. A separate suspension fixture is used for severed-head testing. This system allows rotation and translation of an inverted severed head. The fixture has two sections: a translational platform and a rotational cage that pivots about a point on this platform. The head can be held at any angle in the horizontal or vertical planes. Torso mass and distribution of the torso mass is simulated by weights added to the translational and rotational sections of the fixture. A collar on the lower end of the rotational cage has four pins which fix the specimen at the level of the second thoracic vertebra. The pins set into the vertebral body and both laminae, and fiberglass is used as a potting material. The platform slides along case-hardened shafts via linear ball bushings. These shafts are fixed to an adjustable frame. The frame height and fore-aft positions can be varied based upon the anthropometry of the test specimen. The base of the frame is held in position by sand bags. This fixture is shown in Figure #5.

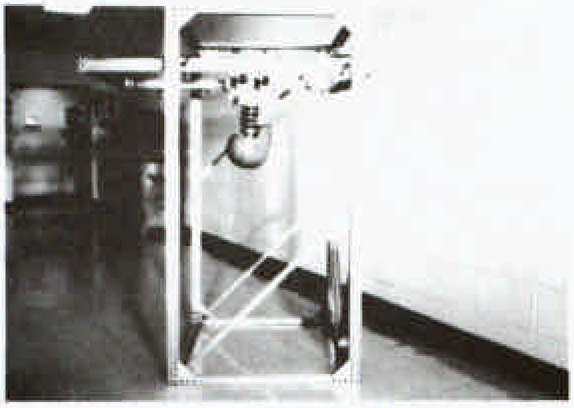

Figure #5: An inverted isolated-head impact fixture and frame, capable of translation and rotation.

Cadaver Preparation

Three cadavers are tested: two whole-body tests (#262 and #299) and one inverted isolated-head test (#480). The whole-body tests are described here. These tests use the WSU 3-2-2-2 instead of the RBKTA, an older version of the trephine sealing systems, a dual-reservoir perfusion device and a single cannula. Cadaver #262 is 82 years old, 68.9 kg and 162 cm. Cadaver #299 is 72 years old, 74.8 kg and 172 cm. Each cadaver receives NDA-3's implanted in the parietal lobes of each hemisphere. CPT's are implanted in the occipital, parietal and frontal lobes. The 3-2-2-2 array is attached to the apex of the head. Each of the trephines are sealed with the thread-insert trephine seal system. The seals and anchor points for the NDA-3's, CPT's and RBKTA do not penetrate below the level of the inner table of the skull so as not to affect the motion of the brain. A representative preparation, just prior to the implant procedure, is shown in Figure #6. An array of seven RDT's is implanted at or near the genu of the corpus callosum, using a frontal or frontal-oblique approach. It is necessary to place the RDT's in a volume no larger than 600 ml so that strain at a point can be approximated. However, the

Figure #6: Whole-body test preparation showing the trephines prior to the implant procedure.

Figure #7: Trephine pattern in frontal region through which the RDT's are introduced.

targets cannot be placed too close to each other as there may be interference in the bi-planar images. Because of the problems of target confusion, a maximum of two sets of seven targets can be inserted into each brain. Radiographs are taken before and after each target insertion. The array is formed by inserting a cannula through a trephine pattern. The trephine pattern consists of four holes positioned at 0, 90, 180, and 270 deg. Each hole is 10 mm from the origin, along the diagonals. A fifth hole is placed at the origin. Each hole is 2.6 mm in diameter. Figure #7 shows a typical target-insertion pattern. The targets are loaded into the cannula, and then the cannula is used to deploy the targets at preset depths. These depths are indicated by a graded pattern on the side of the cannula. The center trephine receives 3 RDT's, at depths of 70, 60 and 50 mm. The four surrounding holes each receive a single RDT at a depth of 60 mm. The trephines are sealed using Teflon tape and lag screws. An improved version of this technique uses thread inserts and O-rings to seal the RDT trephines. A triaxial accelerometer block is then mounted to T1, and a lumbar catheter is inserted to allow pressurization of the cerebral spinal fluid (CSF). Bilateral, ascending and descending, carotid and jugular catheterization is performed so that the arterial and venous systems can be pressurized (100 and 50 mmHg, respectively). Normal saline is used for perfusion in these tests, but the severed head tests use artificial CSF. A radio-opaque marker indicating the anteroposterior, lateral and superior-inferior axes of the head is also mounted on the skull. This marker is a coordinate reference for the head and is used to define the strain tensor. Reference markers are placed on the x-ray image intensifiers as well. Pre-impact x-rays are then taken, as shown in Figure #8.

Figure #8: Lateral pre-impact x-ray showing the NDA-3, CPT and RDT locations.

Testing

An example of the whole-body test configuration is given in Figure #9. Figure #10 shows a fully-prepared head specimen prior to impact. The two cadavers are each impacted twice. Each impact is a posterior blow to the occiput. The impactor face is "padded" with cardboard honeycomb. The impacts are performed at 3 and 6 m/s. Twenty-four channels of data are collected: 9 accelerations from the 3-2-2-2 array, 6 accelerations from 2 NDA-3's, 3 CPT's, impact load and acceleration, impactor gantry acceleration and 3 accelerations at T1. Contact is used as time-zero. Data is acquired by an IDDAS

Figure #9: The whole-body test configuration.

Figure #10: A fully prepared specimen prior to impact. The WSU 3-2-2-2 is mounted to the apex of the head.

(Denton/Somat) which consists of 24 channels of signal conditioners, filters, A/D converters, memory and communications. The portable data acquisition system interfaces well with the parallel-bridged NDA-3's. However, this requires specialized cabling. Prior to beginning the impact sequence, spatial calibration of the cameras is performed using a multi-target calibration cube. Distortion-correction data is obtained by attaching a correction grid to the faces of the image intensifiers. Black level and white balance information is collected when video cameras are used. The impact sequence is controlled by the impactor controller. First, the IDDAS is enabled. Next, the perfusion tanks are opened, and the IDDAS is triggered. Then the cameras are enabled and then started. The x-ray system is energized 70 ms prior to the firing of the impactor. The impactor is fired. Data collected in the IDDAS is transferred to a PC and converted to WSU format. The cadavers are perfused with 10% formalin prior to autopsy.

RESULTS AND DISCUSSION

The images produced during the testing of cadaver #262 are not of suitable quality to resolve the RDT's or NDA-3's. There are problems associated with focus, exposure and field of view. Phantom head tests performed prior to testing #299 help to fine-tune the x-ray and Fastax camera parameters. The images taken when testing #299 prove to be an improvement. However, due to quantum noise, poor contrast ratio and the rotating prisms in the 16 mm film Fastax cameras, the images are not ideal. The RDT's and NDA-3's are intermittently resolvable. However, motion of the brain is clearly distinguishable. Translation, rotation and wave-like motions of the cortex are visible. Because of this, cadaver #299 is perfused with 10% formalin, and the head is removed at the level of T1. The spinal canal is flooded with normal saline. The head is placed inverted in a plastic bag and manually impacted in front of the x-ray system. High-speed video cameras are used instead of the Fastax cameras. The resulting images are far better than the film-based images. Each RDT and NDA-3 is visible throughout the entire test. Subsequent image processing shows that the centroid of each target can be found. Figure #11a is a high-speed video frame of the head just prior to impact. This image is taken from the right-side II, so it is actually a slightly posterior oblique perspective. Note that the image is not negative, as it would be with standard x-ray. The RDT's (eight of them, as there is an additional misplaced target) are seen, as well as the NDA-3's (two of them). The trephine seals and 3-2-2-2 interface are also shown. Figure #11b shows an image of the same head taken during impact. The image is enhanced to show the RDT and NDA-3 positions. The image is processed, the centroids of the RDT's and NDA-3 targets are highlighted, then brightness, contrast and Gamma are returned to the original settings. The Kodak RO cameras currently in use provide images of far greater quality.

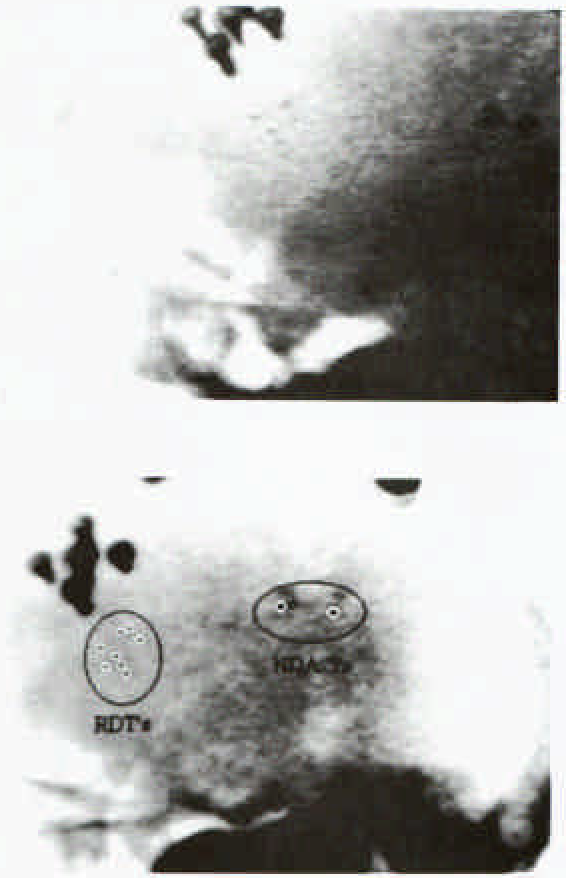

Figure #11a-b: High-speed video images of x-ray image-intensifier output. Pre-impact, unprocessed (a, top), and during impact, processed (b, bottom).

The brains of each cadaver are examined by performing serial sagittal sections. In this way the condition of the tissue surrounding the NDA-3's, RDT's and CPT's can be examined. No relative movement or injury to the brain parenchyma is seen, and the targets are recovered from white matter of right frontal lobe near the genu of corpus callosum. Comparison of pre- and post-impact x-rays corroborates the lack of movement of these devices with respect to surrounding brain tissue. This seems apparent from the high-speed radiographs as well. This substantiates the hypothesis that transducers and targets could be made such that implanting them in human cadaver brain would not cause large amounts of tissue damage, and that these devices would not move through the tissue during impact. Even the tracks left by the cannulas tend to close back around the

NDA-3's and RDT's. The fact that the CPT's also maintain their relative positions and do not damage the surrounding brain tissue suggests that perhaps reduced or neutral density is not required for the targets. This information indicates that lower mass and smaller size targets may be just as useful, if not better, than the difficult to fabricate RDT's. An NDA-3 in brain tissue is shown in Figure #12a. This is an inferior perspective, so the gold ball on the bottom of the NDA-3 is visible. This picture illustrates the lack of damage to the tissue surrounding the NDA-3, and the lack of relative motion of the NDA-3. Figure #12b shows an RDT as it is exposed at autopsy. Note the way the targets seem to be almost fused with the tissue.

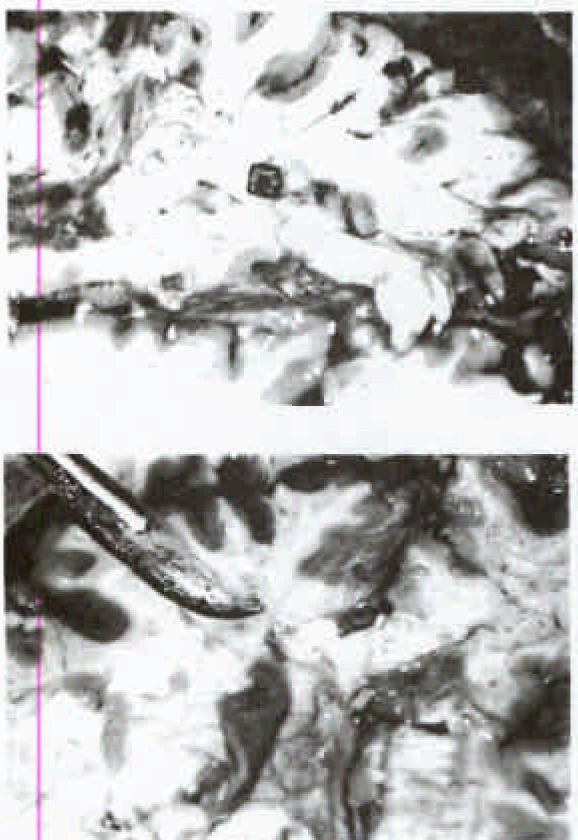

Figure #12a-b: Autopsy results showing firm pocketing of transducers and targets. An NDA-3 (a, top) and an RDT (b, bottom).

The output of the NDA-3's can be compared to the output of the WSU 3-2-2-2 or RBKTA. If the skull is treated as a rigid body, the WSU 3-2-2-2 is used to resolve triaxial accelerations at the initial positions of the NDA-3's. The original orientations of the NDA-3's are found from pre-impact x-rays. The NDA-3 data is then transformed to the WSU 3-2-2-2 coordinate system orientation. Resultant NDA-3 accelerations are determined and compared to WSU 3-2-2-2 data. Relative accelerations are examined in terms of amplitude, phase and frequency. Relative displacements may also be estimated. This lengthy process is underway, but not complete. Figure #13 shows the resultant output of two NDA-3's implanted in the parietal lobes of a single cadaver brain. The initial orientations differ between the two devices. For an occipital blow, as in this case, it is expected that the brain would respond in a somewhat symmetrical fashion, on a gross level, even though the brain is not purely symmetrical. This is reflected in Figure #13.

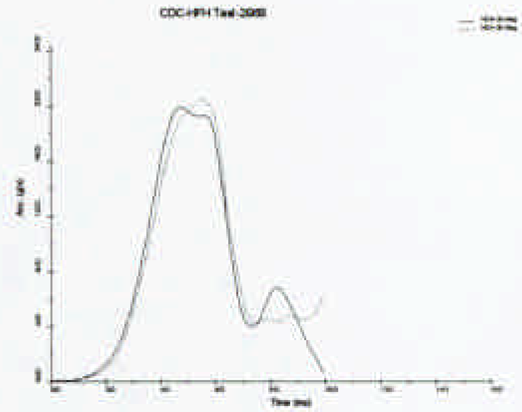

Figure #13: Resultant NDA-3 output comparison.

There are a number of concerns associated with the whole-body testing. The ability to effectively remove air from the cranial space, trapped in either the circulatory system or CSF, is of primary concern. Of equal importance is the ability to prepare the specimen and conduct the test quickly after death, minimizing the amount of time that the body spends out of the cooler, and therefore minimizing autolysis and its effects.

The recently adopted inverted isolated-head approach provides a much improved way of eliminating air. Compression fittings are attached to the carotid arteries and jugular veins. The remaining major vessels are ligated. The vertebral arteries, however, are left open, and are used to bleed air from the circulatory system. Fluid flows from these vessels during the testing. A Tygon tube replaces the dura and spinal cord at the level of the second thoracic vertebra. This tube is used to introduce the artificial CSF and to bleed air from the cranial space. This tube is sealed with a ball-valve quick-disconnect fitting. Just prior to testing, slight pressure can be applied through this fitting using a syringe. The fact that the head is inverted after the instrumentation has been implanted allows the cranial space to be filled with fluid and the air to be evacuated more easily than in the whole-body testing. The dura attachment at T2 is much better than the lumbar catheterization approach. With these improved techniques, a number of the concerns associated with head injury testing are reduced or eliminated.

CONCLUSION

This ongoing study shows that it is possible to develop implantable devices to measure the kinematics of brain injury. Triaxial neutral density accelerometers, reduced density targets and cranial pressure transducers can be used in conjunction with appropriate trephine seals to forward the understanding of head injury. These devices are capable of maintaining their positions with respect to surrounding brain tissue during impact testing.

The use of high-speed bi-planar x-ray and high-speed video imaging techniques allows the determination of the locations of these devices in three dimensions in the impacted human cadaver brain. Therefore, triaxial neutral density accelerometers may be validated, and strain fields within a small volume of brain tissue can be determined .

Improved methods of trephine sealing and perfusion are developed to reduce the possibility of air being trapped within the cranial space. Improved methods of target insertion help minimize the damage done to the brain during the implant process, and help create a more clearly defined array of targets. A newly developed test methodology using an inverted isolated-head approach helps reduce the time between death and testing, helps improve image quality and simplifies transducer connections and wire routing. A thorough analysis of the data obtained in the whole-body and isolated-head tests is forthcoming.

ACKNOWLEDGMENT

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DISCUSSION

PAPER: **Ongoing Investigation of Brain Injury Kinematics**

PRESENTER: Warren Hardy, University of Michigan Transportation Research Institute

QUESTION: Dave Meaney, University of Pennsylvania

I'm intrigued by your reduced density targets and I had a couple of questions and I may have missed it in your presentation. Do you get more than one fast x-ray view or planar view?

ANSWER: Yes. Two. It's bi-axial. Yes. It's 3D.

Q: And, you didn't comment on it but do you have any idea of the types of elongations that you're seeing between these beads?

A: No. Right now one of the problems that we've been concentrating on mostly since previously we've been looking at the neutral density accelerometer issues and we recently moved into the targeting issue is being able to resolve the targets well enough. So, we do have a lot of the data on hand but I haven't really had the opportunity to process a lot of that so I can't answer that question right now and I'm not exactly sure how many there are because we are trying to improve the imaging techniques.

Q: The re-pressurization of the head. You mentioned a little bit about it, and I know people have had some challenges with it in the past. How do you feel about your particular technique?

A: Well, I've been working on refining the technique for an awfully long time. This inverted, severed head sort of arrangement does a couple of things. One very simple, it let's us get the cables out of the way so they are not in view. The other thing is, it allows us to essentially, after we've gone through the dura, we can fill the cranial contents as much as we need to with saline through the simulated spinal column. Then we can re-pressurize the arterial side and I have been able to get a venous return using this and that's basically 1.5 to 2 psi on the arterial side and we'll maybe get back less than 1 psi on the venous side, basically just using a static fluid column for the spinal cord. I'm hoping it's pretty good. I think it's pretty good or it's certainly much better than what we've been doing with the whole body cadaver test.

Q: Guy Nusholtz, Chrysler Corporation

What is the exact method you are using for getting the air out? When I did similar type of work, it generally took me about three hours per cadaver for the test to get all the air out.

A: Yes. It takes an awfully long time. Actually, when we were doing the whole body test, just to give you an example. We get notice of the body let's say Thursday night and we get the blood work back and are ready to go on it by Friday afternoon. It will take me from Friday afternoon all the way straight through to Sunday afternoon over at Henry Ford Hospital to get this thing to fly. That's one of the reasons that we're going to the inverted severed head solution. One of the things that we have looked at is the possibility of using slight vacuum assistance. The other thing is simply constantly changing the orientation of the head. Looking at it under x-ray, we can do that at Henry Ford Hospital quite easily. Looking for the presence of air and making sure that we've got the cranial contents filled as much as possible and that's really the only way that we're able to do it.

Q: The trick that I use is I have very small holes in the skull, sort of pinhole size and you pressurized up from the spinal column and then you just kept taking x-rays, tilting the head until you drove all the air out of the system.

A: That's basically what I was doing before. They weren't exactly pinhole size but I'd say maybe an eighth of an inch or so, but that has previously been the technique.

Q: That gave me the problem pushing the brain up through those holes.

A: Yes. If you are not careful, it is real easy to do that. So, I've kind of gotten away from that.

Q: One other question. How are you comparing your accelerometer array to the internal targets? The accelerometer array is connected to the skull and you are going to have vibrations.

A: Yes. That's one of the things, particularly with the 3222 in a direct impact situation, vibrations can be a problem. It's not so much of a problem, at least on paper it's not, with a rigid body kinematics array which is what we are going to slide into using. But we have used a number of different approaches. We've used the 3222. We've used the SGA. I've had some success with lower speed, slightly padded impactor face occipital hits. I've been comparing the 3222 with NDA's but, agreed, the vibration of the fixture is a problem.

Q: One last question. Do you have any ripple effect on your x-rays or is it completely DC'd out?

A: Any ripple effect on the x-rays?

Q: When the x-ray comes through the subject, it's going to have a 120 cycle on top of it due to the power supply and reduce the intensity of the x-ray.

A: We're not having any difficulty with that. As a matter of fact, we're actually having pretty good luck with all of our images. Using the video, we can hit our subjects with as much energy as we need to. The image intensifiers, it is not a gated system, they are on all the time and they respond up to about 3,000 Hz.

Q: Tony Sances, Medical College of Wisconsin
Did you say the resolution was about 3,000 Hz of the phosphor?

A: That's what Henry Ford Hospital tells me. Yes. That the image intensifiers are good up to about 3,000.

Q: So, have you tried to see whether you could track this?

A: No. The problems we are having are with the Fastax cameras at 1,000 frames per second. I mean that was pretty much the limiting factor. So then, we also used low cams, pinframing camera, 500 frames per second which gives a much better image. But we knew we were going to be moving to video so we were using the in-house system that Henry Ford Hospital had and that only runs up to 240. In about two weeks, we're going to have Kodak Ecktapro RO System on-line and we'll be running that at about 1,000 and I have a feeling that for most of the tests, we're going to be topped out around 1,000.

Q: Is the limitation the recording device or the phosphor in the intensifier?

A: So far, the theory is that it's not the phosphor in the intensifier. It seems to be primarily the combination of the object we are trying to image moving and also the rotating prism in the Fastax moving. That's our best assessment so far.

Q: Thank you.